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Microstructure, texture evolution and mechanical properties of X70 pipeline steel after different thermomechanical treatments

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ABSTRACT

The evolution of microstructure, texture and mechanical properties of API X70 pipeline steel after different thermomechanical treatments has been studied using a combination of X-ray diffraction and electron backscatter diffraction (EBSD). Our investigations revealed that different microstructure consisting of polygonal ferrite, bainite, coarse and fine acicular ferrite grains was obtained with a centre line segregation traversing through and parallel to the rolling direction. EBSD investigations confirmed that both dynamic recovery and partial recrystallization occurred during hot rolling requiring further annealing for a more homogenous equiaxied grain structure. X-ray macro-texture measurement showed relatively a random texture components comprising of Cube, Goss, Brass, S, Copper, R cube and {331} < 1 − 10 > . Texture inhomogeneity during hot rolling were observed for the different processing parameters. The grains at the surface are oriented towards {110}|| ND while the mid thickness has grains mostly oriented in the {001}|| ND with a spread towards the {111}|| ND. We observed that after accelerated cooling, the fast cooling rate and low temperature interruption allows the formation of more bainite which in turn increased the tensile strength of the steel.

1. Introduction

Various techniques have been adopted in improving the mechanical properties of pipeline steels. Some of these include hardness and microstructure controls, as well as modifying the morphology of inclusions [1–4]. Texture control through various thermo-mechanical cycles is a plausible means of producing pipeline steels for enhanced mechanical performance. This is because certain texture components are found to be beneficial to both yield strength and anisotropy of mechanical properties [5–7].

Reports show that the development of crystallographic texture and microstructure in steels can be influenced by thermo-mechanical control rolling parameters [8–10]. These parameters include and not limited to finish rolling temperature, soaking temperature, amount of deformation, and rate of cooling rolled plate. In a study of texture and microstructure of API 5L X100 pipeline steel, Nafisi et al. [6] observed the development of {100} < 110 > , {113} < 110 > and {332} < 113 > texture via different thermo-mechanical paths. In another study, Mohtadi-Bonab et al. [11] showed that {111}|| ND, {112}|| ND and {110}|| ND texture were developed at the near surface planes of an API 5L X70 pipeline steel manufactured using different thermomechanical treatments.

During thermomechanical treatment, hot and warm and rolling is achieved by reducing the temperature of the entire process from 1250 to 850 °C to approximately 1100–700 °C. As a result, hot or warm rolling has been employed for various conditions in alloyed steels. Researchers have discussed the effects of hot rolling processes above and below the non-recrystallization temperature [12–14]. Nafisi et al. [6] studied the effect of different thermomechanical treatments of X100 pipeline. They observed that steel rolled above the non-recrystallization shows mainly banitic ferrite, small amount of quasi-polygonal ferrite and M/A (martensite-austenite) constituents. In another study by Haldar and Ray [15], they observed that warmed rolled extra low carbon steel at 800 °C and 700 °C, showed mainly pancake shaped grains while those rolled at 600 °C and 00 °C, showed elongated ferrite grains with high density of deformation bands. Masoumi et al. [16] observed that the microstructure of an X70 pipeline steel was mainly a banded ferritic-pearlitic structure. Rolling steel below recrystallization temperature give rise to austenite with deformation bands and high density grain boundaries, resulting in grain refinement and transformation of austenite to ferrite phase on cooling while hot rolling within the non-recrystallization region help control texture in hot rolled steel strip and reduce anisotropy of tensile properties [17,18].

Different researches have been done on the development of texture

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in low carbon steel using hot and warm rolling technology [6,8–10]. Venegas et al. [19] reported a near-random crystallographic texture in a hot rolled low carbon pipeline steel, whereas warm rolling was found to enhance the intensity of {111}||ND texture fiber and impact larger amount of strain and high fiber strength. In another study, 30 mm thick steels were warm rolled, austenized at 1050 °C and finished rolled at 560 °C, 620 °C and 640 °C [20]. The authors observed that lower finish rolling temperature led to enhanced mechanical properties, more homogeneous annealed microstructure and the development of {111}//ND texture. It is worth noting that researchers have employed micro alloying elements for texture control [21,22]. Elements like Niobium, Titanium and Vanadium were reported to pin down grain boundaries, hence serve as stabilizing agents during thermo-mechanical treatment of hot rolled steel. Conclusions from the references above show that the elements influence recrystallization, grain growth, austenite-ferrite transformation. And as a result can be used in crystallographic texture control in pipeline steel.

To the best of authors knowledge, the influence of different thermo-mechanical routes on an industrially-manufactured pipeline steels for oil and gas transportation has not been well studied. The present work is aimed to determine the effect of different thermo-mechanical treatments on an industrial API X70 pipeline steel with the overall goal of determining optimum parameters for achieving preferable texture components. Electron backscattered diffraction and X-ray diffractometry techniques were used to analyze the micro and macro-textural evolution during the different thermo-mechanical processing (TMCP).

2. Experimental procedure

In this work, all experiments were carried out on API X70 pipeline steel. The chemical composition of the X70 steel is shown in Table 1.

Two different thermo-mechanical treatments were done by hot rolling of an 8 in. thick ingot and labeled as WE and WD shown in Fig. 1, were applied. The plates were reheated at 1250 °C for 8 h and then rolled in two stages; rough rolling (from 203 mm to 23 mm) and finish rolling (from 203 mm to 9 mm) followed by accelerated and slow cooling to simulate the coiling process. The rough rolling for both WE and WD was started at about 1125 °C and finished ~ 1010 °C in nine passes. For specimen WE, finish rolling was started at 850 °C and finished at 805 °C in four passes and cooled in air from 805 °C to 780 °C in 10 s in air followed by accelerated cooling from 780 °C to 609 °C in 4 s (42.75 C/s). Similarly, finish rolling for specimen WD started at 880 °C and finished at 815 °C in four passes and cooled in air from 805 °C to 780 °C in 12 s in air followed by accelerated cooling from 750 °C to 544 °C in 4 s (51.5 C/s). Final cooling and coiling for WE and WD were carried out at 609–584 °C and 544–500 °C, respectively. Final thickness after rough and finish rolling is 9 mm. Plate specimens for mechanical tensile testing with 25 mm gauge length, 1.5 mm thickness and 6.25 mm width were prepared in the rolling direction from the mid thickness according to ASTM standard E8/E8M-08. The strain rate for the tensile experiment was 0.000787/s. Each test was repeated twice for consistency.

Metallographic preparation of the samples involved a pre-grinding using 320 and 800 SiC grit emery papers, followed by a fine grinding using 9 µm MD-Largo, 3 µm MD-Mol and 1 µm MD-Nap supplied by Struers. Etching was done using the standard 2% Nital (2 vol% nitric acid and 98 vol% alcohol) solution for 15 s. A Nikon MA100 inverted OM and SU6600 Hitachi field emission SEM operated at an acceleration

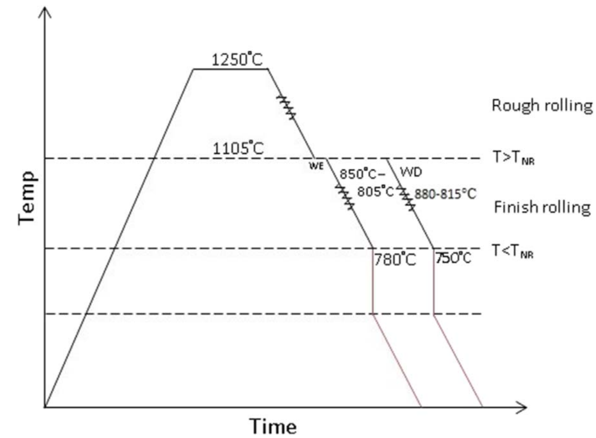

Fig. 1. Two stages of controlled-rolling process for WE and WD specimens.

voltage of 30 kV was used for microstructural analysis. Micro-texture evaluation was conducted using the EBSD technique. SEM equipped with a NordlysNano Oxford detector with an angular resolution of 0.1°, was used to collect EBSD patterns. EBSD patterns with a binning of 8 × 8 pixels were acquired by AZTEC 2.0 data acquisition software. Channel 5-Oxford Instruments software was used for the post processing of the collected EBSD patterns. In the recrystallization fraction analysis, $1^\circ < \theta < 7.5^\circ$ is the misorientation angle (θ) considered to separate sub grains while $\theta > 7.5^\circ$ was considered to separate grains. If the average angle in a grain exceeds 7.5°, the grain is classified as being "deformed". Subgrains whose internal misorientation is under 7.5°, but the misorientation from subgrain to subgrain is above 7.5°, in that case the grain is classed as "substructured".

Macro-texture evaluation of the specimens was conducted using Bruker D8 advance diffractometer with an area detector system and Cr K_α radiation. For orientation distribution function (ODF) calculations, we used two pole figures for BCC ferrite {(110), (200)}. We further treated these measured pole figures with Resmat TexTools to calculate the ODFs and inverse pole figures.

3. Results and discussion

3.1. Microstructural study

The room temperature micrographs of WE and WD specimens at the mid cross-section of plate after finishing rolling are shown in Fig. 2a and b, respectively. The microstructure of both WE and WD is not homogenous and consist of polygonal ferrite, bainite, coarse and fine acicular ferrite grains. The presence of fine acicular ferrite and bainite is more pronounced in WD specimen which could be attributed to the fast cooling rate. The role of TMCP on microstructural evolution can be attributed to the difference that exist between the two different treatments. In this case, finish rolling and cooling rate. The role of finish rolling temperature has been reported as a means of improving strength and deformation texture in steels [23] while cooling rate helps to control microstructural products and also affects the intensity of transformation textures [24]. From our current study, the fast cooling rate and low temperature interruption led to more bainite and acicular ferrite in WD specimen, while the difference between the finish rolling temperatures is small and is not expected to cause significant difference between the two specimens.

Table 1
Chemistry of the material (wt%).

C	Mn	S	P	Si	Cu	Ni	Cr	V	Cb	Mo	Sn	Al	SoAl	Ca	B	Ti	N	O	Ce	CE
0.047	1.65	0.0018	0.009	0.18	0.29	0.07	0.06	0.001	0.073	0.247	0.010	0.044	0.036	0.0014	0.0001	0.022	0.0099	0.003	0.0002	0.2495